

A STUDY OF THE ECONOMICS OF THREE TYPES OF FRAMES FOR INDUSTRIAL BUILDINGS

BY
MEHMET FUAT TIGRAK

B. S., University of Illinois, 1942

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY IN ENGINEERING
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PREFACE

The selection of the type of frame and the frame spacing which will lead to the most economical design is the first and most important step for the designing engineer.

To the writer's knowledge, there are no data available on the relative economy of different types of steel frames, or their most favorable spacing by which the engineer may be guided in the design of large industrial buildings.

The writer would like to contribute to the profession some data resulting from his investigation of three different types of steel frames for large industrial buildings.

I. INTRODUCTION

1.—SCOPE OF THE THESIS.

Three spans, 200ft-0 in, 250ft-0 in, 300ft-0 in, were considered, and for each three types of steel frame were studied: a truss-column frame, a three-hinged truss frame, and a two-hinged truss frame. For each span and type of frame, different bay lengths were studied, as follows:

For the 200ft-0 in span bay lengths of 30ft-0 in; 40ft-0 in; 50ft-0 in

For the 250ft-0 in span bay lengths of 30ft-0 in; 40ft-0 in; 50ft-0 in

For the 300ft-0 in span bay lengths of 40ft-0 in; 50ft-0 in; 60ft-0 in

2.—OBJECT OF THE THESIS.

(a) The primary objects of this study were the determination of the following:

(1) The bay length requiring the least amount of steel for each type of frame for each span considered in this study.

(2) The relationship between span and bay length for the greatest economy of each type of frame included in the investigation.

(3) The type of frame and bay length which will have the least weight of steel for each span.

(b) Secondary objects included the study of numerous relationships; for example, weight vs. span; weight vs. panel load; horizontal thrust vs. span; horizontal thrust vs. panel load, and others.

II. PROPORTIONING & TRIANGULATION OF THE STRUCTURES

3.—PROPORTIONING

The proportions of all the types of frames and the longitudinal trusses were based on constant ratios and factors so there would be a valid basis for comparison.

4.—TRIANGULATION

The Warren type of web triangulation was used for all the types of frames, and for the longitudinal trusses.

III. STRESS ANALYSIS

5.—ANALYSIS OF STRESSES IN THE FRAMES

To simplify and systematize the necessary analyses the stresses in the members were determined for the following loads:

- (a) 1.0kip at each top panel point
- (b) 1.0kip at each bottom panel point
- (c) 1.0kip at each top panel point for one half of the frame
- (d) 1.0kip per foot of height wind load on one side of the frame
- (e) Horizontal reaction of 1.0kip

Panel concentrations due to dead load, live load, and wind load were determined for each type of frame and for each bay length.

These data enabled easy determination of dead load stresses for any distribution of weight between the top and bottom chords; live load stresses for panel loads of any magnitude, either over the whole truss or over one-half thereof; wind stresses due to a uniform wind load of any magnitude acting on either side;

and finally stresses due to a horizontal reaction of any magnitude resulting from a change in temperature.

The wind stress analyses of the truss column frames were based on the assumption that the truss could be considered infinitely stiff in comparison with the columns.

Influence lines for horizontal thrust in the two hinged frames were determined as follows:

The bending moment at the center of the frame, due to assumed panel loads, was determined from a relation (established by investigation) between that moment and the bending moment at the center of a simple beam having the same span as the frame. This enabled calculation of the horizontal reactions (or tie rod stress) and of the stresses in the members. The members were then designed and the movements of the panel points and supports, due to a unit horizontal reaction, determined from a Williot diagram. From these movements the influence lines for vertical and horizontal loads were established.

The trial designs were made for large panel loads (100 kips at each top chord panel point) in order to obtain stresses large enough for convenient designing. Since the relative movements of the various points on the frame, due to a unit horizontal reaction, are dependent on the relative areas of the members, rather than the actual areas, the influence lines determined from large panel loads are correct for the loads used for final design.

In all the frames the stresses resulting from the most unfavorable combination of the dead load, live load, and wind load, and from temperature change when effective, were used as the basis for design. In accordance with usual practice permissible stresses were increased when stresses from wind loads were included with other stresses. However, in the two-hinged frames no increase in permissible stress was allowed when stresses resulting from temperature changes were included with those from dead load and live load.

IV. DESIGN

6.—DESIGN LOADS

The structures were designed for the following loads:

Roof and surface 40lbs. per sq. foot

Equivalent snow and wind 35 lbs. per sq. foot

Wind pressure on vertical exposed areas 35 lbs. per sq. foot

Weight of structure as estimated for each case.

7.—SPECIFICATION

As stated in the thesis the designs were made in accordance with the specification adopted by the American Institute of Steel Construction and published in its manual "Steel Construction".

Minor changes were made in the specification, but were not sufficient to affect the results obtained.

8.—PROPORTIONING OF THE MEMBERS

In order to eliminate the effect of variation in weight resulting from the use of excess metal to secure harmony in proportions, all members were carefully designed to obtain the smallest practicable area to resist the calculated stresses.

However, in order to determine what differences might have resulted from designing each frame as a harmonious whole, one frame of each type considered was designed giving careful attention to the relations between the various members.

9.—GUSSET PLATE THICKNESSES

The gusset plate thicknesses were checked against shear and bending at the L₂ joints of the simple trusses.

V. SUMMARY AND RESULTS

10.—DISCUSSION OF THE RESULTS

The results of the investigation were presented in tables and diagrams too numerous and voluminous for reproduction here, but the following abstracts from the "Discussion of Results" present the significant findings.

Within the limitations of this study, the following observation may be made:

(a) Relating to All Three Types of Frames.

(1) It has been found that the two-hinged frames require the least amount of steel per foot of building. The economy of material will be increased if the foundations are able to resist the horizontal thrust, thus permitting elimination of the tie rod.

(2) The two-hinged frames require the following percentages of the steel, per foot of building required for the truss-column frames:

For the clear span of 200ft 0 in.....87.7%

For the clear span of 250ft 0 in.....90.5%

For the clear span of 300ft 0 in.....94.6%

(3) The three-hinged frames require the following percentages of the steel required for the corresponding truss-column frames:

For the clear span of 200ft 0 in.....90.7%

For the clear span of 250ft 0 in.....92.6%

For the clear span of 300ft 0 in..... 97.7%

These results indicate that the saving of material decreases as the span of the frames increases. Furthermore, the rate of decrease is not linear and seems to become rather large with increase in span.

(4) The economical bay length for any type of frame is a function of the span. The rates of change of these functions are not linear and the rates of change decrease with the increase in span of the frames.

(5) The weights of the horizontal portions of the two-hinged frame were about 67.8%, and the weights of the corresponding portions of the three-hinged frames about 62.0%, of the weight of the truss-column frames.

Thus the horizontal portions of the two-hinged frames were about 5.8% heavier than the corresponding portions of the three-hinged frames.

(6) The relationship between the weights of vertical parts of the two-hinged frames (Type C) and the weights of columns of the truss-column frames (Type A) appears to be a function of the span. The observed relationship is as follows:

For 200ft 0 in, clear span Type C vertical parts 9.2% less

For 250ft 0 in, clear span Type C vertical parts 6.1% greater

For 300ft 0 in, clear span Type C vertical parts 21.4% greater

(7) The weights of the vertical parts of the three-hinged frames (Type B) are greater than the weights of columns of the truss-column frames. The amount of this difference appears to be a function of the span, and the data obtained so far are as follows:

For the clear span of 200ft 0 in.....5.0%

For the clear span of 250ft 0 in.....19.8%

For the clear span of 300ft 0 in.....36.8%

(8) The weights of the vertical parts of two-hinged frames (Type C) are less than the weights of the vertical parts of the three-hinged frames. The difference is not constant, changing with the change in span. The following values were obtained:

For the clear span of 200ft 0 in.....13.9%

For the clear span of 250ft 0 in.....11.5%

For the clear span of 300ft 0 in.....11.1%

(b) Relating to the Truss-Column Frames.

The following observations may be made:

(1) The relation between total weight of frame and the span is almost linear.

(2) The relation between total weight of the frame and the bay length for a particular span is linear.

(3) The relationship between the total weight of the frame and the total weight of the longitudinal trusses supported by the frame for a particular span is linear.

(4) The ratio of the weight of the horizontal truss to the total weight of the frame increases with the increase in the span, and at a constant rate.

(5) The ratio of the weight of the columns to the total weight of the frame decreases with the span, and at a constant rate.

(6) The rate of the increase of the weight of the horizontal truss is equal to the rate of decrease of the weight of the columns.

(7) The ratio of the weight of the columns to the weight of the horizontal truss decreases with increase in the span and at a constant rate.

(c) Relating to the Three-Hinged Frames.

The observation made for truss-column type frames are valid also for the three-hinged frames.

(d) Relating to the Two-Hinged Frame.

Study of the data obtained for the two-hinged frames indicates the relations observed for the truss-column and three-hinged frames apply also to the two-hinged frames.

It may be observed that in this study the depth of the two-hinged frame at the center was made one-half that at the center lines of the supports, and the latter depth was arbitrarily made the same as the corresponding depth of the truss-column frame.

There are no data known to the writer to support either of these choices, and it is entirely possible that some other depth at the center line of support or some other ratio of center depth might lead to more economical results.

There is a need for further study of this type of frame, and the same points might well be studied in the three-hinged frame.

(e) The Moment at the Center of the Two-Hinged Frames.

The moment at the center of the span may be represented by KM in which K is a fraction and M is the moment at the center of a simple beam having the same span as the frame. From the data obtained in this study, there seems to be reason to suppose that K is an inverse function of the span of the frame.

(f) Partial Loading Effect.

It seems fair to observe that whenever partial loading appears to be possible, in dealing with frames such as were considered in this thesis, investigation of the center diagonals in all frames and the top and bottom chords near the quarter-point in three-hinged or two-hinged frames, should be sufficient. The severity of the partial loading used by the writer emphasizes this observation.

(g) Wind Stresses.

It does not seem necessary to make a general investigation of wind stresses in such frames as were considered here, particularly if the wind load is assumed to be less than 30 pounds per square foot. Of course this observation does not apply to the columns or chords at the ends of the trusses in the truss-column frames.

(h) Temperature Stresses.

In the investigations so far made temperature stresses were not found to be of much importance. Temperature stresses amounting to 11%, 6.4% and 3.3% of the stresses to live load plus dead load were found in the chords at the center and diagonals at the end in the two-hinged frame with 200ft 0 in clear span. Since the temperature changes assumed by the writer were rather severe it would seem reasonable for practical purposes to estimate the temperature stresses in the center panel only.

VITA

Mehmet Fuat Tigrak was born in Istanbul, Turkey, on August 26, 1911. He finished the grade school in 1924. He graduated from the military lycee "Kuleli" in 1930. He served for six months with a battalion of combat engineers as a prerequisite for entrance to War Academy.

He entered the War Academy in October 1930, graduated in May 1932, and received a commission of Second Lieutenant.

He was sent to Engineers Corps officers training school in 1932 and graduated from this school in August 1934.

After graduation he was assigned to Engineer Corps troops, and served for two years in this post.

He was then assigned to fortification construction in western Turkey, and on August 30, 1936 was promoted to the rank of First Lieutenant.

In September 1936, he was assigned to the military factories in Ankara, Turkey, where he received basic training in the manufacture of different products.

In June 1937, he was sent to the University of Berlin, Germany, for further engineering training, where in May 1938, he was assigned to construction projects of buildings and subways. On October 1, 1938, he was admitted to the Technische Hochschule (College of Engineering) in Berlin. However, due to the outbreak of the second World War, he had to return to Turkey in August 1939.

He was assigned to various military projects in Turkey in 1939 and 1940, and later sent to Robert College to attend courses in English, preparatory to assignment in the United States. In November 1940, he was admitted to the University of Illinois.

In August 1941, he was promoted to the rank of Captain.

Majoring in structural engineering, he received the degrees of B. S. in C. E. in 1942, and M. S. in 1943.

He completed his second year of residence in February 1944, and passed his preliminary examinations for the Ph. D. He then worked for three months in soil surveys and testing, and six months as inspector and testing engineer at the University of Illinois Airport.

